

***Annual Report LWS TR&T Focus Science Topic (FST) team:
Flare Particle Acceleration Near the Sun and Contribution to Large SEP Events***

Team Annual Report: July 1, 2009 - August 30, 2010

PI	Investigation title
Ben Chandran, UNH	Stochastic particle acceleration in solar flares
Judy Karpen, GSFC	3D MHD Modeling of Flare Reconnection for Solar Energetic Particle Acceleration
Glenn Mason, JHU/APL (team leader)	Understanding Propagation Characteristics of Heavy Ions to Assess the Contribution of Solar Flares to Large SEP Events
Nariaki Nitta, LMSAL	Solar Flares as a Source of Gradual Solar Energetic Particle Events
Gerry Share, UMd, NRL	Comparison of Accelerated Particle Populations at 1 AU and at the Sun
Allan Tylka, NRL	The Disappearance of Large, Fe-Rich Solar Energetic Particle Events in the Declining Phase of Cycle 23: Implications for the Role of Flares

Third Year Activities:

Team meetings held:

- FST meeting #3, October 25-26, 2009, at Morse Hall, University of New Hampshire, Durham, NH
- FST meeting #4, July 25, 2010, Santa Fe, NM.

Agendas with list of attendees are below.

A bibliography of team member activities is below.

The third year activities by team members were as follows:

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Ben Chandran (UNH) with Martin Lee and Chung-Sang Ng, and 2 graduate students:

During the third year of this project, we made the following progress:

- We developed a quantitative theory for the stochastic heating of ions by low-frequency, strong Alfvén wave turbulence. We showed that such turbulence is very inefficient at accelerating ions to high energies in solar flares, but offers a promising mechanism for explaining ion heating in coronal holes and the solar wind. We published two papers on this in the *Astrophysical Journal*.
- We carried out hybrid simulations of ions interacting with fast magnetosonic wave turbulence, and demonstrated that ions can be effectively heated by Bernstein modes that are produced by cascading fast-wave turbulence. We published a paper on this in the *Astrophysical Journal*.
- We continued to collaborate with Judy Karpen's group to analyze the properties of turbulence in global numerical simulations of solar flares, for constraining theories of stochastic particle acceleration in solar flares. We hope to publish a first paper on our results within the coming year.
- We continued to develop the Wave Particle Kinetic Code for simulating resonant interactions between high-frequency waves and ions, and hope to be able to model stochastic particle acceleration in solar flares using this code within the coming year.
- We carried out a series of investigations of turbulence and wave-particle interactions in the solar wind, which were related to (but not the primary focus of) this project

Judy Karpen (GSFC) with Spiro Antiochos (GSFC), Rick DeVore (NRL), and Ben Lynch (UC Berkeley SSL):

- We have developed postprocessing software that derives key turbulence parameters from our 3D MHD simulations of the flare reconnection in the corona below breakout coronal mass ejections (CMEs). We used an existing, moderately well-resolved simulation as a testbed for testing and refining our methodology, before proceeding (in the next few months) to perform a much more computationally intensive breakout simulation with better resolution targeted to the flare current sheet and post-eruption loops. The spatial extent of the region to be analyzed and the times of interest are specified by examining the simulation output and determining where and when small-scale structure appears to predominate in the velocity field. We identified two zones for further analysis: (1) a lower region extending in height between the top of the post-eruption loops and the flare reconnection site and approximately the latitudinal and azimuthal extent of the model filament channel (region of high magnetic shear); and (2) an upper region where the flare reconnection jet interacts with the back of the CME plasmoid.
- We focused our attention on the lower region, and measured the following quantities: average mass density, average velocity and magnetic field in each spatial component (r ,

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θ , ϕ); root mean square velocity and magnetic field; average thermal pressure, magnetic pressure, plasma β , and Alfvén speed; average velocity and magnetic-field fluctuations in each spatial component; root mean square velocity and magnetic field fluctuations; the decompositions of the velocity and magnetic-field fluctuations along and perpendicular to the local magnetic field direction; the average total and root mean square of the parallel velocity fluctuation; the minimum magnetic-field magnitude and minimum perpendicular velocity fluctuation; the average vorticity fluctuation in each spatial component and the root mean square vorticity fluctuation; the average parallel and perpendicular dilatation fluctuations and their root mean square values. In addition, we computed the spatial correlation integrals along the local magnetic field, along the perpendicular velocity, and in the direction orthogonal to both, of the parallel and perpendicular velocities, vorticity, and parallel and perpendicular dilatation. The resulting correlation lengths (the e-folding values of the above correlations) indicate the characteristic scales of the ambient turbulence, and their relative magnitudes indicate the nature of the underlying waves (e.g., Alfvénic, magnetoacoustic, fast vs. slow, etc.). The implications of these results for stochastic particle acceleration are being determined by our UNH colleagues, Ben Chandran and his graduate student, Peera Pongkitiwanichakul, and we plan to submit a joint publication within the next 6 months.

- We began discussing with Allan Tylka (NRL) the derivation of shock properties near the Sun from our breakout CME simulations. However, progress on this topic requires the incorporation of a solar wind in our model, which is expected to be finished within FY11.

Glenn Mason (APL) with C. M. S. Cohen and R. A. Mewaldt (Caltech), Gang Li (Univ. of Alabama in Huntsville), M. I. Desai (SWRI), D. K. Haggerty (APL), R. A. Leske (Caltech), and G. Zank and O. Verkhoglyadova (Univ. of Alabama in Huntsville):

- We continued team telecons every week or two, and implemented adiabatic deceleration into the code. The deceleration was done to cover the case of focused transport, thereby avoiding the usual assumption of isotropy used in earlier analytical formulations of the problem. The adiabatic deceleration addition produced odd features in the code, and an extensive series of checks was taken to see if this behavior was indeed correct. Part of the problem stemmed from the fact that although the observations and Parker spiral are in a “fixed” frame, the scattering of the particles takes place from magnetic field irregularities that are moving with the solar wind speed. Thus, in the Monte-Carlo section of the code, it is necessary to do a frame transformation from fixed to SW frame before each scatter, and then to transfer back again to the fixed frame after the scatter.
- We compared calculation results in both the fixed and “solar wind” frame, seeking to identify any inconsistencies (the two results should be similar for particle speeds above ~ 1 MeV/nuc since the solar wind speed is negligible in that case). These checks revealed

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some errors in the code that have been fixed, and the resulting code appears to be working as expected.

- We are additionally checking these results versus published results (e.g., Kocharov et al. *Solar Phys.*, 1998 vol. 182 pp. 195) and the agreement appears to be good. We are also beginning to carry out more specific checks with a code developed by J. Giacalone and E. Chollet, and will carry out special runs for that purpose. The codes being checked are not identical, and each makes certain assumptions for the calculation. We believe that by carrying out such checks we will gain important insight into the sensitivity of the calculation to assumptions and approximations.
- We also expanded collaborations with Gerry Share Ronald Murphy, and other members of the RHESSI team working to interpret neutral particle signatures (neutrons, gamma-rays, and ENAs) that provide remote information on SEPs accelerated in flares. This has resulted in presentations at the 9th Astrophysics Conference and AGU Meeting of the Americas. We are now carrying out simulations of possibility that flare-accelerated neutron-decay protons and electrons contribute seed particles to CME-driven shocks, and we are using RHESSI gamma-ray and interplanetary SEP data to evaluate and compare the populations of protons accelerated by the flare and the CME-driven shock in the same SEP event.

Nariaki Nitta (LMSAL) with Marc DeRosa (LMSAL) and Christina Cohen (Caltech), and collaborators Dave Chenette (LMSAL), Mike Kaiser (GSFC), and Säm Krucker (UC Berkeley SSL).

- We spent a significant amount of effort in characterizing Ground Level Enhancement (GLE) events. They are high-energy SEP events in which GeV ions interact with the Earth's atmosphere and produce secondary particles to be detected above the galactic cosmic ray background. This work is in conjunction with the Coordinated Data Analysis Workshop (CDAW) on Ground Level Enhancement (GLE) events that the PI co-organized with Dr. Nat Gopalswamy (NASA/GSFC) in January 2009 at the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, CA. We note that the hybrid SEP events tend to have harder spectra than normal gradual SEP events and that some of the hybrid events are also GLE events.
- Our goal is to find characteristic properties of active regions that host GLE events. This could be a general question of what produce energetic CMEs and flares, which would be addressed elsewhere regardless of GLE or SEP events. Therefore we chose to conduct a statistical study to contrast GLE active regions with others in two control groups, namely active regions associated with SEP events but not GLE events, and active regions with delta configuration without SEPs. We analyzed SOHO MDI data and extracted basic properties such as unsigned total flux of the active region. The difference among the three groups of active regions is small, but GLE active regions tend to contain enhanced

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magnetic flux close to the polarity inversion line (a high “R” value as outlined in Schrijver 2007), and they also show smaller separations of positive and negative polarities than regions associated with non-GLE SEP events.

- GLE events are often characterized by quick onsets in neutron counts corresponding to high-energy SEP flux. This is used to advocate their “flare” origin. But this temporal behavior can simply mean that the source region is well connected to the Earth. Using the standard technique of the potential field source surface (PFSS) model, we find that five of the 10 GLE producing active regions contain open field lines and that two regions opened up a day or two after the GLE event. This may simply indicate the limitation of the model but can contain the information on the active region dynamics even though the model itself is static. The GLE events seen in closed regions tend to show slower onsets. We will need to quantify this.
- The study of GLE events, although important, may not directly concern the main question of the project, that is, to understand the origin of the “hybrid” events in terms of the two outstanding hypotheses, direct contributions of flare particles (Cane et al. 2006) and manifestations of different shock conditions (i.e., quasi-perpendicular as opposed to quasi-parallel for normal SEP events, Tylka et al. 2005). In order to see how viable the latter hypothesis is, we started to explore the possibility that the hybrid SEP events enhanced in Fe may come from the shock flank, where the quasi-perpendicular conditions may be more easily met. In order for the CME flank to be an efficient accelerator, it has to expand. We know that coronal waves in EUV are often associated with rapid CME lateral expansion. We have started testing the hypothesis that “hybrid” SEP events are correlated with EUV waves

Gerry Share (UMD, NRL), with Ron Murphy (NRL), Jim Ryan (UNH) and Allan Tylka (NRL):

- We have used newly developed nuclear-line templates (Murphy et al. 2009) along with improved detector response functions for *SMM* and *RHESSI* to determine the compositions and spectra of flare-accelerated particles that interact in the solar atmosphere. We have found that a coronal composition for accelerated particles heavier than He best fits the spectra in three of the four flares studied. In only one flare is an impulsive SEP composition a better fit. We also find that the average flare-accelerated α/p ratio is about a factor of two higher than the photospheric $^4\text{He}/\text{H}$ ratio and that heavy nuclei are enhanced by about the same factor relative to the sum of α 's and p's.
- We have shown that there are at least 4 particle acceleration/interaction episodes in the 2005 January 20 flare. This work was enabled by recent improvements in the RHESSI response matrix. The episodes include:
 - 1) an impulsive phase with electron/ion acceleration;

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- 2) a phase when protons reach energies > 300 MeV;
- 3) a phase with electrons >2 -5 MeV and a very hard 3-50 MeV ion spectrum; and
- 4) an extended phase lasting several hours where the 50-500 MeV ions have a spectral index similar to that observed in space.

Phase two may be coincident with the ejection of SEP ions.

- We have calculated the spectrum of low-energy neutrons produced in solar flares and show the neutrons with energies >10 MeV are produced even in interactions of 2 MeV/nucleon ions. Using these calculations we question the reported detection of 1-8 MeV neutrons from the 2007 December 31 flare by MESSENGER.
- We have observed nuclear gamma-rays from an M2 flare in Cycle 24. The measured ion spectrum at the Sun is softer than the particle spectrum observed in space.
- Analysis of the Ground Level Event on 20 January 2005 was completed at the University of New Hampshire and formed the basis of Trevor Morgan's Doctoral Dissertation. The Coronas/SONG high-energy gamma-ray data were used as a surrogate for energetic-ion precipitation in the flare and assumed to represent the ejection of energetic particles for the ground level enhancement. However, the relative timing of the gamma-ray signal and the GLE intensity, and the abrupt turn-on of the GLE, make such an assumption problematic because coronal diffusion would produce a slow rise in the GLE, a feature that is not observed. Dr. Morgan concludes that the evolution of the GLE spectrum and anisotropy is consistent with a shock-acceleration scenario.

Allan Tylka (NRL) with Ed Cliver (Air Force Research Lab) and William Dietrich (NRL consultant):

- We completed a study of relativistic electrons in ground level events. The study compared proton measurements from neutron monitors and satellites in GLEs with measurements of relativistic electrons (>1 MeV) from the Cosmic Ray Nuclei Experiment on IMP8. The CRNE had never been calibrated for electrons and we performed a GEANT4 Monte Carlo simulation in order to quantify its electron response (Novikova et al. ASR, 46, 31-43, 2010) In our comparisons based on ~ 30 GLEs observed between 1973 and 2005, we found
 - 1) a tight correlation between event-integrated fluences of >1 GV protons and >1 MeV electrons;
 - 2) nearly simultaneous times of first arrival of relativistic protons and relativistic electrons at Earth; on average, relativistic electrons arrived 1.2 minutes after the relativistic protons, but this delay is likely to be the result of systematic

biases in the electron observations, such as viewing angles limited to the ecliptic plane;

- 3) fitted e-folding rise times for relativistic protons and electrons nearly the same in all events, even though the rise times varied by more than order of magnitude from event to event;
- 4) a clearly ordering in power-law spectral indices in which for 33 events, the electron spectral index at > 1 MeV was softer than that of protons at 10-100 MeV and harder than that of protons > 1 GeV.

Taken together, these observations favor a common accelerator for relativistic electrons and protons in GLEs. These results were presented in at COSPAR 2010. A journal paper is in preparation.

- We completed a detailed comparison of the two ground-level events in the historical record (1976 April 30 and 2006 December 13) that occurred at (or nearly at) solar minimum when the monthly smoothed sunspot number was less than 15. Both events were well observed by the world-wide neutron monitor network. The 1976 event was also observed by particle instruments on IMP8; the 2006 event was observed by Wind, ACE, SOHO, and GOES. We found that the general particle characteristics of these two GLEs – spectral shape, time profiles, and heavy-ion composition – were not significantly different from each other or from GLEs that occur at other times in the solar cycle. The most noteworthy difference between the two GLEs was their relative sizes. This difference is consistent with the notion that the coronal suprathermal seed population from activity in the days before the event plays a critical role in the production of GLEs. This study has been published in the Proceedings of the SOHO23 conference (Tylka & Dietrich, ASP Conference Series 428, 329-333, 2010).
- We have requested and received a one-year no-cost extension on our work in order to complete an additional task outlined in our proposal, namely a large statistical study of the SEP productivity of CMEs during various phases of Cycle 23.

Contributions and collaborations for the FST effort

The primary joint FST effort has been between teams led by Judy Karpen, Nariaki Nitta, and Ben Chandran, where the observational researchers are working to help constrain the parameter space being investigated by Ben Chandran's group. Other efforts are also listed below.

1) Characterizing bulk turbulence in flaring regions. Ben Chandran (lead) with Judy Karpen, and their CoIs. The turbulence investigations of Ben Chandran's group cover a very wide range of local conditions, and so would benefit from constraints on flare properties provided by numerical models and observations. The MHD models used by Judy Karpen's group have been used to calculate bulk properties such as average plasma speeds parallel and perpendicular to the local magnetic field, and various moments in turbulent regions near the termini of the flare reconnection jets. By this means, the global models provide a context for the relatively small scale sizes associated with the turbulence calculations, and yield critical input and tests for stochastic particle-acceleration models. We hope to publish a first paper on our results within the coming year

2) Comparison of x-ray images from SEP-productive and non-SEP-productive CMEs. Nariaki Nitta (lead) with Allan Tylka and Judy Karpen their CoIs. One of the major team efforts as the PI understands is to evaluate the relative importance of CME shocks and flare processes in the production of large SEP events. With some of the FST team members, we tried to compare the properties of fast CMEs that do and do not produce gradual SEP events. It is found that as long as the CME is faster than 1500 km/s and the source region is in the western hemisphere, we have at least some SEPs. If the CME is slower (but has to be quite fast, e.g., $v > 800$ km/s) or the source region is in the eastern hemisphere, then EUV or X-ray images are found to be useful to let us know a possible SEP event. We have found SEP events often associated with large-scale disturbances, as better captured by low coronal images as dimming and waves

3) Particle properties of gamma-ray events. Gerry Share (lead) with Allan Tylka, Glenn Mason and their CoIs. The FST has identified gamma-ray flares in Cycles 23 and 24 where direct comparisons with the properties of SEPs and conditions at the Sun and in the inner heliosphere can be made. The four best candidates for this study are the 2003 October 28 and November 2, 2005 January 20, 2006 December 13, and 2010 June 12 flares observed by RHESSI and by Fermi. Detailed work is underway in the analyses of the January 20 and June 12 flares. With the high sensitivity of the Fermi telescope we can compare for the first time the characteristic of ions above 300 MeV/nucleon in moderate sized gamma-ray flares with measurements in space.

4) Shock characteristics at $\sim 2.5 R_s$. Allan Tylka (lead) and Judy Karpen and their CoIs. This group is investigating the potential of the Karpen et al. CME model to deliver shock characteristics in the range of 2-10 solar radii, which might provide useful inputs for SEP

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acceleration and transport codes. As noted above, further code development is underway that will enable meaningful shock properties to be derived from the CME simulations.

Next meeting

The FST has completed its 3-year study, with the final meeting having been held at Santa Fe, NM, July 2010.

Presentations

Presentations from all the meetings held to date have been put on the Caltech FTP site at: hassif.srl.caltech.edu/pub/LWS_Mason/ Folders are:

- FST_meeting_June_2008
- FST_meeting_Jan_2009
- FST_meeting_Oct_2009
- FST_meeting_July_2010

Ph.D. thesis supported (in part):

Morgan, T., “Milagro and Neutron Monitor Measurements of the 2001 April 15 and 2005 January 20 GLEs”, PhD Thesis University of New Hampshire, 2010 July

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LWS TR&T Focus Science Topic (FST) Team Meeting:

**Flare Particle Acceleration Near the Sun and
Contribution to Large SEP Events**

Morse Hall, Room 301

Univ. of New Hampshire, Durham, NH 03824

MAP AND DIRECTIONS AT:

<http://www.eos.unh.edu/about/durham.shtml>

October 25-26, 2009

Sun Oct 25		
1:00 PM	Mason	Welcome
1:15 PM	Ryan	logistics
Progress reports on investigations:		
1:30	Chandran	Stochastic particle acceleration in solar flares
2:00	Karpen	3D MHD Modeling of Flare Reconnection for Solar Energetic Particle Acceleration
2:30	Mason	Understanding Propagation Characteristics of Heavy Ions to Assess the Contribution of Solar Flares to Large SEP Events
3:00	3:30	break
3:30	Nitta	Solar Flares as a Source of Gradual Solar Energetic Particle Events
4:00	Share	Comparison of Accelerated Particle Populations at 1 AU and at the Sun
4:30	Tylka	The Disappearance of Large, Fe-Rich Solar Energetic Particle Events in the Declining Phase of Cycle 23:

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		Implications for the Role of Flares
5:00		Group discussion
5:30	Adjourn	Group dinner at 6:00
Mon Oct 26		
Progress reports on collaborative FST efforts:		
9:00	Chandran	(with Karpen, Nitta and CoIs): Characterizing bulk turbulence in flaring regions
	Nitta	(with Tylka, Karpen and CoIs): Comparison of x-ray images from SEP-productive and non-SEP-productive CMEs
	Share	(with Tylka, Mason, Karpen and CoIs): particle properties of gamma-ray events
	Tylka	(with Karpen and CoIs): shock characteristics at ~2.5 Rs
Contributed talks --		
	PM	
Mewaldt	30 min	Spectra and properties of Ground-Level events during solar cycle 23
Mewaldt	30 min	Comparison of flare and interplanetary accelerated particles
Murphy	30 min	Nuclear cross sections for gamma-ray deexcitation line production from the Earth's atmosphere
Morgan	30 min	Milagro observations of Jan 2005 and April 2001 SEP events

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Mason	30 min	3He rich SEPs from nearly quiet Sun
Tylka	30 min	3He/4He ratios in relativistic solar electron events
3:30		Continue discussions from yesterday
		Splinter groups
		Set date for next meeting
~4:30	adjourn	

Investigator teams:

Chandran

Karpen, CoIs: Antiochos

Mason, CoIs: Cohen, Mewaldt, Li, Desai, Haggerty; Collaborators: Leske, Zank

Nitta, CoI: Cohen

Share, CoIs: Ryan, Murphy; Collaborators: de Nolfo

Tylka, CoIs: Cliver, Dietrich

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LWS TR&T Focus Science Topic (FST) Team Meeting:

**Flare Particle Acceleration Near the Sun and
Contribution to Large SEP Events**

**Stiha Room
La Fonda Hotel
100 E. San Francisco St.
Santa Fe, NM 87501**

DIRECTIONS AT:
<http://www.lafondasantafe.com/about/directions.html>

Sunday, July 25, 2010

Meeting schedule:	
9:30 AM	Morning session starts
10:45	Break
12:30PM	lunch
1:30	Afternoon session starts
3:30	Break
~5:30	adjourn
Progress reports on investigations:	
Chandran	Stochastic particle acceleration in solar flares
Mason	Understanding Propagation Characteristics of Heavy Ions to Assess the Contribution of Solar Flares to Large SEP Events
Share	Comparison of Accelerated Particle Populations at 1 AU and at the Sun
Nitta	Solar Flares as a Source of Gradual Solar Energetic Particle Events -- Nariaki arrives after ~11:30

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Progress reports on collaborative FST efforts:	
Chandran	(with Karpen, Nitta and CoIs): Characterizing bulk turbulence in flaring regions
Nitta	(with Tylka, Karpen and CoIs): Comparison of x-ray images from SEP-productive and non-SEP-productive CMEs
Share	(with Tylka, Mason, Karpen and CoIs): particle properties of gamma-ray events
Contributed talks --	
Mason	Effects of IP transport on SEPs with differing charge to mass ratios
Mason (for Li)	Studying Transport of Heavy ions in SEP events
Share / Murphy	Update on Gamma-Ray Observations of the 2005 January 20 Solar Flare
Share / Murphy	Gamma-ray Observations of the 2010 June 12 Solar Flare
Share / Murphy	Low-Energy Neutrons Observations in the Inner Heliosphere
Mewaldt	Solar-flare neutrons and ENAs as a source of energetic seed particles for CME-driven shocks
Ryan	Milagro and Neutron Monitor Measurements of the 2001 April 15 and 2005 January 20 GLEs
Cohen	Time Dependent Composition in Large Solar Energetic Particle Events

Investigator teams:

Chandran

Karpen, CoIs: Antiochos (unable to attend)

Mason, CoIs: Cohen, Mewaldt, Li, Desai, Haggerty; Collaborators: Leske, Zank

Nitta, CoI: Cohen

Share, CoIs: Ryan, Murphy; Collaborators: de Nolfo

Tylka, CoIs: Cliver, Dietrich (unable to attend)

PUBLICATIONS 2009-2010:

- B. Chandran, P. Pongkitiwanichakul, P. Isenberg, M. Lee, S. Markovskii, J. V. Hollweg, B. Vasquez, "Resonant Interactions Between Protons and Oblique Alfvén/Ion-Cyclotron Waves in the Solar Corona and Solar Flares," *Astrophysical Journal*, accepted
- B. Chandran, "Alfvén Wave Turbulence and Perpendicular Ion Temperatures in Coronal Holes," *Astrophys. J.*, 720, 548 2010.
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- B. Chandran, E. Quataert, G. Howes, J. Hollweg, & W. Dorland, "The Turbulent Heating Rate in Strong MHD Turbulence with Nonzero Cross Helicity," *Astrophys. J.*, 701, 652 2009.
- E. E. Chollet, R. A. Mewaldt, A. C. Cummings, J. T. Gosling, D. K. Haggerty, Q. Hu, D. Larson, B. Lavraud, R. A. Leske, A. Opitz, E. C. Roelof, C. T. Russell, J.-A. Sauvaud, "Multi-point Observations of the May 2007 Solar Energetic Particle Events", To be published in *JGR*, 2010.
- Dayeh, M. A., M. I. Desai, J. R. Dwyer, H. K. Rassoul, G. M. Mason, and J. E. Mazur, "Composition and Spectral Properties of the 1 AU Quiet-Time Suprathermal Population During Solar Cycle 23," *Astrophysical Journal*, vol. 693, pp 1588-1600, 2009, doi: 10.1088/0004-637X/693/2/1588
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- J. Hollweg, S. Cranmer, & B. Chandran, "Coronal Faraday Rotation Fluctuations and a Wave/Turbulence-Driven Model of the Solar Wind," *Astrophys. J.*, submitted

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- S. Markovskii, B. Vasquez, & B. D. G. Chandran, "Perpendicular Proton Heating Due to Energy Cascade of Fast Magnetosonic Waves in the Solar Corona," *Astrophys. J.*, 709, 1003 2010.
- Mason, G. M., N. V. Nitta, C. M. S. Cohen, and M. E. Wiedenbeck, "Solar Energetic Particle ^3He -rich events from the nearly quiet Sun in 2007-2008", *Astrophys. J. (Letters)*, 700, L56-L59, July 2009.
- Morgan, T., "Milagro and Neutron Monitor Measurements of the 2001 April 15 and 2005 January 20 GLEs", PhD Thesis University of New Hampshire, 2010 July
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- Murphy, R.J. Kozlovsky, B., Share, G.H., "Nuclear Cross Sections for Gamma-Ray Deexcitation Line Production by Secondary Neutrons in the Earth's Atmosphere", submitted to *Journal of Geophysical Research*, 2010.
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Verkhoglyadova, O.P., G. Li, G.P. Zank, Q. Hu, and R.A. Mewaldt, Using the PATH code for modeling gradual SEP events in the inner heliosphere, *ApJ*, 693, 894-900, 2009.

O. P. Verkhoglyadova, G. Li, G.P. Zank, Q. Hu, C. M. S. Cohen, R. A. Mewaldt, G. M. Mason, D. K. Haggerty, T. T. von Rosenvinge, and M. D. Looper, “Understanding Large SEP Events with the PATH Cod: Modeling of the December 13, 2006 SEP Event”, Submitted to *ApJ*, 2010.

Watanabe, K., Lin, R.P., Krucker, S., Murphy, R.J., Share, G.H., *et al.*, “Physics of ion acceleration in the solar flare on 2005 September 7 determines g-ray and neutron production”, *Advances in Space Research*, 44, 789-793, 2009

INVITED TALKS:

B. Chandran, “Heat transport and instabilities in galaxy-cluster plasmas,” APS Meeting, Dallas, Texas, May, 2009

B. Chandran, “The Origin of the Solar Wind,” University of Arizona, April, 2010

B. Chandran, “Ion Acceleration in Solar Flares,” SHINE Workshop, Santa Fe, NM, July, 2010

Desai, M. I., M. A. Dayeh, F. Allegrini, & G. M. Mason, “Solar Cycle Variations of Quiet-time Suprathermal and CME-shock Accelerated Ions,” *Invited Paper (30 min)*, Presented at the 8th Annual International Astrophysics Conference, Shock Waves in Space and Astrophysical Environments, May 1-7, 2009, Big Island, Hawaii.

Desai, M. I., M. A. Dayeh, M. A. Lee, C. S. Smith, and G. M. Mason, “Shock acceleration of hot ion populations”, INVITED Plenary Talk, 30 min, ACE / SOHO / STEREO / Wind Symposium, Kennebunkport, Maine, June 8-11, 2010.

Mason, G. M., N. V. Nitta, C. M. S. Cohen, and M. E. Wiedenbeck, “³He-rich SEPs from a Nearly Quiet Sun in 2007-2008”, INVITED talk (30 min) presented at the NSF SHINE 2009 Workshop, August 3-7, Wolfville, Nova Scotia, Canada.

Mewaldt, R. A., M. D. Looper, D. L. Haggerty, C. M. S. Cohen, G. M. Mason and J. E. Mazur, “Spacecraft Measurements of SEP Energy Spectra for Ground-Level Events of Solar Cycle 23”, INVITED Talk presented at the 1st LWS Workshop on Ground-Level Events, Palo Alto CA, January 2009.

Mewaldt, R. A., E. E. Cholle, C. M. S. Cohen, J. Giacalone, D. K. Haggerty, and G. M. Mason.,

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“Neutron-Decay Protons and ENAs as a Source of Seed Particles for CME-Driven Shocks”, INVITED talk, 9th Astrophysics Conf, Kaanapali, Maui, HI, March, 2009

Mewaldt, R. A., “New Views of Solar Energetic Particles and Coronal Mass Ejections”, Charles P. Swann Lecture, University of Delaware, April 22, 2009. INVITED

Mewaldt, R. A., “Observation and Interpretation of Energetic Neutral Hydrogen Atoms from the December 5, 2006 Solar Event”, INVITED Seminar at the Space Sciences Laboratory, University of California at Berkeley, August 16, 2009.

Share, G.H., “*Properties of accelerated particles at the Sun from gamma-ray and neutron measurements*”, 38th COSPAR Assembly, Bremen, Germany, July 2009.

Verkhoglyadova, O. P., G. Li, G. P. Zank, Q. Hu, C. M. S. Cohen, G. M. Mason, D. K. Haggerty, T. T. von Rosenvinge, M. D. Looper, “Proton and heavy ion spectra at 1 AU in the SEP event of December 13, 2006”, Voyagers in the Heliosheath, Observations, Models, and Plasma Physics, Kauai, Hawaii, Jan. 9-14, 2009.

Wiedenbeck, M. E., G. M. Mason, R. Gómez-Herrero, D. Haggerty, N. V. Nitta, C. M. S. Cohen, E. E. Chollet, A. C. Cummings, R. A. Leske, R. A. Mewaldt, E. C. Stone, T. T. von Rosenvinge, R. Müller-Mellin, M. I. Desai, U. Mall, “Multipoint observations of 3He-rich SEP events since the launch of STEREO”, INVITED Talk, ACE / SOHO / STEREO / Wind Symposium, Kennebunkport, Maine, June 8-11, 2010.

CONFERENCE PROCEEDINGS:

Cohen, C. M. S., G. M. Mason, R. A. Mewaldt, E. E. Chollet, E. R. Christian, A. C. Cummings, M. I. Desai, A. W. Labrador, R. A. Leske, E. C. Stone, T. T. von Rosenvinge, and M. E. Wiedenbeck, “Time dependent composition in the December 2006 SEP events”, Proc. 31st International Cosmic Ray Conference, paper 1305, Łódź, Poland, July 7-15, 2009.

Dietrich, W. F., A.J. Tylka, and E.W. Cliver, “3He/4He Enhancements in Relativistic Solar Electron Events”, Proc. 31st International Cosmic Ray Conference, paper 0497, Łódź, Poland, July 7-15, 2009.

P. A. Isenberg, B. J. Vasquez, B. D. G. Chandran, and P. Pongkitiwanichakul, “Quasilinear Wave ‘Reflection’ Due to Proton Heating by an Imbalanced Turbulent Cascade,” in Proceedings of the Solar Wind 12 Conference, M. Maksimovic, K. Issautier, N. Meyer-Vernet, M. Moncuquet, & F. Pantellini, ed., American Institute of Physics Conference Series, 1216, 64 2010.

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- Kartavykh, Y. Y., W Dröge, B. Klecker, G. M. Mason, E. Möbius, M. Popecki, and S. Krucker, “Diagnostics of interplanetary and flaring plasmas in impulsive solar energetic particle events,” *Bull. Russian Academy Sci: Physics*, 73, 291-293, 2009.
- Li, G., R. A. Mewaldt, and C. M. S. Cohen, “Can Multiple Shocks Trigger Ground Level Events?”, 31th International Cosmic Ray, Lodz, Poland 2009.
- S. Markovskii, B. Vasquez, & B. Chandran, “Hybrid Simulations of Energy Cascade among Fast Magnetosonic Waves in a Cold Plasma,” in Proceedings of the Solar Wind 12 Conference, M. Maksimovic, K. Issautier, N. Meyer-Vernet, M. Moncuquet, & F. Pantellini, ed., American Institute of Physics Conference Series, 1216, 68, (2010)
- Mewaldt, R. A., M. D. Looper, D. L. Haggerty, C. M. S. Cohen, A. W. Labrador, R. A. Leske, G. M. Mason, and J. E. Mazur, “Spectra and properties of ground-level events during solar cycle 23”, Proc. 31st International Cosmic Ray Conference, Łódź, Poland, July 7-15, 2009.
- Mewaldt, R. A., R.A. Leske, A.Y. Shih, E.C. Stone, A.F. Barghouty, C.M.S. Cohen, A.C. Cummings, A.W. Labrador, T.T. von Rosenvinge and M.E. Wiedenbeck, “Observation and Interpretation of Energetic Neutral Hydrogen Atoms from the December 5, 2006 Solar Flare”, 31st International Cosmic Ray Conference, Lodz, Poland 2009.
- Mewaldt, R. A., R. A. Leske, A. Y. Shih, E. C. Stone, A. F. Barghouty, C. M. S. Cohen, A. C. Cummings, A. W. Labrador, T. T. von Rosenvinge, and M. E. Wiedenbeck., “Observations and Interpretations of Energetic Neutral Hydrogen Atoms from the December 5, 2006 Solar Event”, Twelfth International Solar Wind Conference, AIP Conference Proc. CP 1216, M. Maksimovic, et al., eds., AIP, 2010, p. 592-595.
- P. Pongkitiwanichakul, B. D. G. Chandran, P. A. Isenberg, and B. J. Vasquez, “Resonant Interactions Between Protons and Oblique Alfvén/Ion-Cyclotron Waves,” in Proceedings of the Solar Wind 12 Conference, M. Maksimovic, K. Issautier, N. Meyer-Vernet, M. Moncuquet, & F. Pantellini, ed., American Institute of Physics Conference Series, 1216, 72 2010.
- Tylka, A.J. and W.F. Dietrich, “Ground-Level Enhanced (GLE) Solar Particle Events at Solar Minimum”, Proceedings of SOHO-23: Understanding a Peculiar Solar Minimum, ASP Conference Series 428, 329-333 2010.
- Tylka, A.J. and W.F. Dietrich, “A New and Comprehensive Analysis of Proton Spectra in Ground-Level Enhanced (GLE) Solar Particle Events”, Proc. 31st International Cosmic Ray Conference, paper 0273, Łódź, Poland, July 7-15, 2009
- Wiedenbeck, M. E., G. M. Mason, R. Gómez-Herrero, D. H. Haggerty, N. V. Nitta, C. M. S. Cohen, E. E. Chollet, A. C. Cummings, R. A. Leske, R. A. Mewaldt, E. C. Stone, T. T.

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von Rosenvinge, R. Müller-Mellin, M. I. Desai, and U. Mall, “Multipoint observations of ^3He -rich solar energetic particle events using STEREO and ACE, Proc. 31st International Cosmic Ray Conference, Łódź, Poland, July 7-15, 2009.

Wiedenbeck, M. E., G. M. Mason, R. Gómez-Herrero, Dennis Haggerty, N. Nitta, C. M. S. Cohen, E. Chollet, A. C. Cummings, R. A. Leske, R. A. Mewaldt, E. C. Stone, T. T. von Rosenvinge, R. Müller-Mellin, M. I. Desai, and U. Mall, “Observations of ^3He -rich solar energetic particle events over a broad range of heliospheric longitudes: results from STEREO and ACE”, Proc. Solar Wind 12 Conference, Saint-Malo, France, June 21-26, 2009; AIP Conf. Proc. #1216, p 621-624, 2010.

CONTRIBUTED TALKS:

B. Chandran, “Resonant Interactions Between Protons and Oblique Alfvén/Ion-Cyclotron Waves in the Solar Corona and Solar Flares,” Solar Orbiter Workshop, Sorrento, Italy, 2009.

Christian, E. R., T. T. von Rosenvinge, C. M. S. Cohen, A. C. Cummings, R. A. Leske, G. M. Mason, R. A. Mewaldt, E. C. Stone, and M. E. Wiedenbeck, “Testing the origin of hybrid solar energetic particle events”, paper SH22A-02, AGU meeting, San Francisco, CA, Dec. 14-18, 2009.

Cohen, C. M. S., G. M. Mason, R. A. Mewaldt, E. E. Chollet, E. R. Christian, A. C. Cummings, M. I. Desai, A. W. Labrador, R. A. Leske, E. C. Stone, T. T. von Rosenvinge, and M. E. Wiedenbeck, “Time dependent composition in the December 2006 SEP events”, presented at the 31st International Cosmic Ray Conference, Łódź, Poland, July 7-15, 2009.

Cohen, C. M. S., A. J. Tylka, G. M. Mason, R. A. Mewaldt, D. V. Reames, “Time dependent composition in large solar energetic particle events”, paper SH22A-01, Fall AGU meeting, San Francisco, CA, Dec. 14-18, 2009.

Desai, M. I., M. A- Dayeh, F. Allegrini, G. Li, G. M. Mason, R. A. Leske, R. A. Mewaldt, and M. A. Popecki, “Solar cycle variations of quiet-time suprathermal and CME-shock accelerated ions”, presented at the STEREO-3/SOHO-22 Workshop, Bournemouth, England, April 27 - May 1, 2009.

Desai, M. I., C. Smith, M. A. Lee, G. M. Mason, M. A. Dayeh, “Temporal evolution of energetic particles and magnetic field waves near CME-driven shocks”, 38th COSPAR Scientific Assembly, Bremen, Germany, July 18-25, 2010.

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- DeVore, D. R., J. T. Karpen, & S. K. Antiochos, “Simulations of Flare Reconnection in Breakout Coronal Mass Ejections”, 2009 meeting of the Solar Physics Division, American Astronomical Society, 14-18 June 2009, Boulder CO.
- Guo, Z., E. Möbius, M. Popecki, B. Klecker, and G. M. Mason “Solar energetic particle events with high iron charge state throughout ACE SEPICA energy range”, presented at the NSF SHINE Workshop, Wolfville, Nova Scotia, Canada, Aug. 3-7, 2009.
- Guo, Z., E. Möbius, B. Klecker, M. Popecki, and G. M. Mason, “Solar Energetic Particle events with high iron charge state at low SEP energies”, presented at the New England Section of American Physical Society and AAPT Joint Fall Meeting, Lewiston, Maine, Oct. 3-4, 2009.
- Li, G., G. M. Mason, D. K. Haggerty, R. A. Mewaldt, C. M. S. Cohen, R. A. Leske, M. I. Desai, M. A. Dayeh, G. Zank, and O. Verkhoglyadova, “Heavy ions as probe of solar wind MHD turbulence in SEP events” American Geophys. Union Joint Assembly, Toronto, Canada, May 24-27, 2009, *EOS, Trans. AGU, 90*, Jt. Assem. Suppl., Abstract SH23A-05.
- G. Li, G. M. Mason, R. A. Mewaldt, C. M.S. Cohen, R. A. Leske, M. I. Desai, M. A. Dayeh, D. K. Haggerty, O. Verkhoglyadova, G. P. Zank, “Studying transport of heavy ions in SEP events”, N.S.F. SHINE Workshop, Santa Fe, New Mexico, July 26-30, 2010.
- Mewaldt, R. A., M. D. Looper, D. L. Haggerty, C. M. S. Cohen, A. W. Labrador, R. A. Leske, G. M. Mason, and J. E. Mazur, “Spectra and properties of ground-level events during solar cycle 23”, presented at the 31st International Cosmic Ray Conference, Łódź, Poland, July 7-15, 2009.
- Mewaldt, R. A., C. M. S. Cohen, A. W. Labrador, R. A. Leske, G. M. Mason, and A. Vourlidas, “Composition and Properties of Ground-Level Events”, presented at the First LWS Workshop on Ground-Level Events, Palo Alto CA, January 2009.
- Mewaldt, R. A., M. D. Looper, D. L. Haggerty, C. M. S. Cohen, A. W. Labrador, R. A. Leske, G. M. Mason, and J. E. Mazur; “Update on Spectra and Properties of GLE Events during Solar Cycle 23”, 2nd GLE Workshop, University of Alabama at Huntsville, Nov 16-18, 2009.
- Mewaldt, R. A., E. Chollet, C. M. S. Cohen, and G. M. Mason, “Solar flare neutrons and ENAs as a source of energetic pickup ions for acceleration by CME-driven shocks”, CSPAR 9th Annual International Astrophysics Conf., “Pickup ions Throughout the Heliosphere and Beyond”, Maui, Hawaii, March 14-19, 2010.

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- Mewaldt, R. A. E. E. Chollet, C. M. S. Cohen, J. Giacalone, and G. M. Mason, “Solar-flare neutrons as a source of energetic seed particles for acceleration by CME-driven shocks”, N.S.F. SHINE Workshop, Santa Fe, New Mexico, July 26-30, 2010.
- Mewaldt, R. A., M. D. Looper, D. L. Haggerty, C. M. S. Cohen, A. W. Labrador, R. A. Leske, G. M. Mason, and J. E. Mazur, “Spectra and properties of ground-level events during solar cycle 23”, AGU Meeting of the Americas, Foz do Iguaçu, Brazil, August 8-13, 2010.
- Mewaldt, R. A., C. M. S. Cohen, E. Chollet, J. Giacalone, D. K. Haggerty and G. M. Mason, “Can Solar-Flare Neutrons Provide Energetic Seed Particles for Acceleration by CME-Driven Shocks?”, *AGU Meeting of the Americas*, Foz du Iguaçu, Brazil, August 12, 2010, SH43A-09.
- Murphy, R., B. Kozlovsky, J. Kiener, and G. Share, “Nuclear Gamma-Ray Deexcitation Lines and Continuum from Accelerated-Particle Interactions in Solar Flares”, D13.0005, April 2009 APS Meeting
- Share, G. H., and R. J. Murphy, “Using Gamma-Ray Line Observations to Determine the Chromospheric Neon/Oxygen Abundance Ratio”, 40th Solar Physics Division Meeting, Boulder, 2009.
- Tylka, A.J., W.F. Dietrich, and E.I. Novikova, “Relativistic Electrons in Ground-Level Enhanced (GLE) Solar Particle Events”, COSPAR 2010, Bremen, Germany, 18-25 July 2010,
- Tylka, A.J., W.F. Dietrich, and W. Atwell, “Band Function Representations of Solar Proton Spectra in Ground-Level Events”, COSPAR 2010, Bremen, Germany, 18-25 July 2010.
- Verkhoglyadova, O. P. , G. Li, G. P. Zank, Q. Hu, C.M.S. Cohen, R. A. Mewaldt, G.M. Mason, D. K. Haggerty, T. T. von Rosenvinge, and M.D. Looper, Modeling of a large SEP event of December 13, 2006 with PATH code”, paper EGU2009-2250, presented at European Geosciences Union General Assembly 2009, Vienna, Austria, April 19-24, 2009.
- Verkhoglyadova, O. P., G. Li, G. P. Zank, C. M. S. Cohen, R. A. Mewaldt, G. M. Mason, D. K. Haggerty, T. T von Rosenvinge, M. D. Looper, “Understanding near-Earth energetic particle environment during large SEP events with the PATH code”, paper SH33A-1489, AGU meeting, San Francisco, CA, Dec. 14-18, 2009.
- Wang, L., R. P. Lin, and G. M. Mason, “When and where impulsive SEPs are accelerated”, presented at the ACE / SOHO / STEREO / Wind Symposium, Kennebunkport, Maine, June 8-11, 2010.

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Wiedenbeck, M. E., G. M. Mason, R. Gómez-Herrero, Dennis Haggerty, N. Nitta, C. M. S. Cohen, E. Chollet, A. C. Cummings, R. A. Leske, R. A. Mewaldt, E. C. Stone, T. T. von Rosenvinge, R. Müller-Mellin, M. I. Desai, and U. Mall, “Multipoint observations of ^3He -rich solar energetic particle events using STEREO and ACE”, presented at the 31st International Cosmic Ray Conference, Łódź, Poland, July 7-15, 2009.

Zhao, L., G. Li, G. M. Mason, R. A. Mewaldt, M. I. Desai, M. A. Dayeh, C. M. S. Cohen, R. A. Leske, D. K. Haggerty, O. P. Verkhoglyadova, G. P. Zank, “Heavy ions transport in selected SEP events”, paper SH22A-03, AGU meeting, San Francisco, CA, Dec. 14-18, 2009.

Z. Guo, E. Möbius, R. Popecki, and G. M. Mason, “SEP charge states”, presented at the ACE / SOHO / STEREO / Wind Symposium, Kennebunkport, Maine, June 8-11, 2010

CONFERENCE SESSIONS AND WORKSHOPS ORGANIZED:

Coordinated Data Analysis Workshop (CDAW) on Ground Level Enhancement (GLE) events in January 6-9, 2009 at the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, CA. workshop organized by N. Nitta with Dr. Nat Gopalswamy (NASA/GSFC)

Impulsive ^3He -rich events, 2009 NSF Shine Workshop, Wolfville, Nova Scotia, August 3-7, 2009; session organized and chaired by D. Haggerty

Observational tests of Suprathermal Particle Acceleration Theories. 2009 NSF Shine Workshop, Wolfville, Nova Scotia, August 3-7, 2009; session organized and chaired by M. Dayeh

How Much do Solar Flares Contribute to Large SEP events at Earth? 2010 NSF Shine Workshop, Santa Fe, New Mexico, July 26-30, 2010; session organized by M. Desai and D. Haggerty, discussion leaders G. Mason and G. Share.

“Extreme Energetic Particle Events from the Sun”, Special Session at the AGU “Meeting of the Americas, Foz du Iguassu, Brazil, August 12, 2010; Richard Mewaldt was head convener

AGU Fall 2010 meeting -- sessions with coveners who are CoIs on this grant:

- (1) Acceleration and Transport of SEPs, session convener Gang Li
- (2) New Views of Solar Energetic Particles, coveners Dennis Haggerty, Richard Mewaldt